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Industrial/Commercial Refrigeration - System Trends and Strategic Conservation Potential

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Energy efficiency issues in the industrial/commercial refrigeration sector were examined through a literature search and interviews of industry representatives. Emphasis was placed on energy consumption and demand reduction potential of existing and emerging technologies and equipment. Highest potential demand reductions involved the retrofitting of computerized refrigerant and defrost controls, head pressure controls, parallel, unequal compressor (rack) systems, and passive cooling systems.

1.0 INTRODUCTION

Conventional refrigeration equipment used in the industrial and commercial sector in Canada is predominately of American design and manufacture. A direct result of this influence is the poor energy-efficiency performance of this equipment under the cooler climatic conditions found here and in the northern U.S. In many cases, refrigeration equipment is run under artificially loaded conditions, in order to compensate for deficiencies in mechanical controls and crude designs that are targeted mainly for service in warmer climates.

With the current interest in efficiency and conservation, many innovative controls and systems coming on the market offer energy and demand savings. Many of these are retrofittable and cost effective, and have been researched and tested by federal agencies in both Canada and the U.S.A.

The abundance of new equipment makes it difficult for the user to choose hardware that best meets his needs and also operates efficiently. In this report, an attempt is made to survey available systems and controls that best suit the Canadian market in terms of electrical demand reduction, and to a lesser degree, energy efficiency. From this list, potential candidates for utility strategic-conservation efforts can be drawn.

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2.0 HARDWARE AND SYSTEMS

For the purposes of this report, refrigeration systems and hardware are limited to applications other than comfort cooling or heating. This excludes applications normally associated with HVAC systems. Refrigeration equipment applied "commercially" is often very similar to hardware found in "industrial" applications, with, perhaps, an increasing of system capacity. (One exception would be the occurrence of ammonia-based systems in the industrial, but not the commercial, sector.) Therefore, in order to cover as many applications as possible, emphasis was placed on 'commercial' equipment, although in most cases the findings apply equally well to 'industrial' applications.

For the sake of brevity, it is assumed that the reader is familiar with the hardware, systems and nomenclature used in this report. Detailed descriptions of the hardware and systems used in the refrigeration industry and discussed in this report can be found in reference /1/.

To determine the current state of the refrigeration industry, and the direction it is going, in terms of energy demand and efficiency, two distinct methods of information retrieval were tried. The first involved a computerized literature search of appropriate engineering databases containing brief project descriptions, references, etc. The second approach involved contacting key people in the industry in order to determine what they felt was being done or is likely to be done. This provided a more local and 'practical' source of information.

3.0 LITERATURE SEARCH

Three key-word literature searches were carried out in late 1987. Information sources scanned included a general database covering private and government agencies throughout the industrialized nations. A Department of Energy (DOE) and an Electric Power Research Institute (EPRI) database were also separately scanned. Relevant items were limited to work published since 1979.

The three database searches resulted in over 400 references meeting the selection criteria. Further filtering reduced this to 88 references, which are listed under references 9 to 96 inclusively.

Several contemporary articles and reports /1,2,3,4,5,6,7,8/ were also reviewed to give an overall feel for the current state of the industry.

It was found that all the relevant work being carried out in the refrigeration field could be summarized under three general sectoral categories: retailing/food service, warehousing/storage and processing. A brief summary of the findings is listed under each sector, below.

RETAILING/FOOD SERVICE

Floating head pressure control

Significant energy and peak load savings can be had during periods when ambient temperatures are low. A floating head pressure control allows the condenser pressure (and compressor discharge pressure) to drop when the ambient air temperature drops and results in increased system efficiency. Energy savings and peak load reductions increase as the ambient temperature

decreases. Some studies show energy savings as high as 15%, in milder climates than southern Ontario's. It could be expected that energy savings here could be higher along with a corresponding reduction in peak load.

Floating head pressure controls are available on the market now and are easily field-retrofitted, although some engineering and replacement of expansion valves may be required to fully realize the potential savings. This becomes necessary on machines that have expansion valves of a size or design that prevents them from passing enough refrigerant for the machine's capacity at the lower pressure difference which will exist when the condenser is running cooler.

Electronic Expansion Valves

A product that is just becoming available, this device allows more precise metering and control of the refrigerant. Compared to traditional designs, the electronic expansion valve requires almost no pressure differential across it in order to function properly and is not sensitive to head pressure levels. These attributes make it especially attractive when incorporated with head pressure controls.

Little field experience has been obtained with this hardware to date. Capital costs are high (compared to standard valves) and control and sensing circuitry is required. However, expectations for energy savings and peak load reductions are also high, and could easily pay for the added hardware cost. More field experience is needed to establish reliability performance.

The application of electronic expansion valves is more likely to be for new equipment, and likely be mated with floating head pressure controls.

Parallel, Unequal Compressor Systems

In this technique, banks of 3 or more compressors of unequal capacities (equipped with appropriate controls) are set to meet varying refrigerant loads by turning off individual compressors.

Tests have shown reductions in energy consumption as high as 30% compared to a single-compressor system. Energy and peak load reductions are linked to the variability of the refrigeration load but in most cases peak load reductions will be achieved at colder ambient temperatures, and may result in a higher percentage reduction in peak load than in energy.

Systems are available and there is a wealth of field experience with them, although it is not thought of as a retrofit option in most cases. First-cost premiums are not excessive, and pay-back periods are short. One important advantage of this type of system is the convenience of not suffering a total loss of refrigeration capacity if one compressor fails.

Variable-Speed Compressor Control

An electronic variable-speed drive can be coupled to a refrigeration motor-compressor to vary the compressor speed in response to refrigeration load. The effect is similar to the parallel, unequal compressor system (see above).

There is little field experience with this system to date, although the prime components (electronic variable-speed motor drives) have been in use for many years. Energy and peak load reduction potential is similar to that of the parallel, unequal compressor systems. This may

be a more attractive option for retrofit applications, but questions arise surrounding the ability of existing designs of motor and compressor to tolerate variations in operating speed. More field experience is needed, especially with hermetically sealed compressor systems.

Glass Doors and Strip Curtains

These devices are used to reduce the heat gain in refrigerated enclosures while allowing easy viewing and/or access to the contents of the enclosure.

The hardware and technology has been in place for years and there are proven energy and peak load reductions, in some cases up to 50%. What appears initially as an easy retrofit may actually turn out to be an involved procedure if maximum benefit is to be obtained. Changes in controls, compressor sizing and defrosting algorithms are usually required. In addition, in retail food marketing, there may be customer or employee resistance to some types of strip curtain installations.

Overall, this is a worthwhile option to consider. Some studies cite other savings associated with increased food storage life and increased sales.

Defrost Improvements

Improperly designed or operating defrost controls are a frequent weak point in many systems. Adaptive (electronic) defrost controls are available for both retrofit and OEM applications. Energy and peak load reduction potentials are attractive.

Since they are a low capital cost item, retrofitting these new adaptive defrost controls may be justified in a majority of systems currently in use. However, there is little field experience with these devices as they are just moving out of the prototype stage.

Desiccant dehumidification is a concept that could significantly reduce the need for defrosting. Again, little field experience or hardware is available now, and it may not prove economically feasible in our climate.

Good Refrigeration Practices

Under this category are included items that normally should be followed in designing, maintaining, and operating the refrigeration system. However, sometimes the best intentions fail due to uncontrollable circumstances or events.

Suction line pressure drops should be minimized as approximately one psi drop is equivalent to a 1% drop in efficiency. Correct pipe sizing, low-pressure-drop evaporator pressure regulators, and the proper application of liquid subcooling should all be attended to.

Often, a properly-designed defrost system becomes less effective because of changes made to other components or parts of the system. Whenever a reduction in compressor loading is made, associated adjustments to the defrosting system should be made.

Studies have shown that good general maintenance programs can and do reduce energy consumption (and no doubt, demand too). A review, by qualified personnel, of older refrigeration systems can usually turn up deficiencies that can be economically rectified.

WAREHOUSING/STORAGE

All the items discussed under the preceding category apply here, in addition to the following:

Evaporative Pre-coolers for Air-Cooled Condensers

Evaporative pre-coolers reduce the temperature of the air supplied to air-cooled condensers by evaporating water into the air. The cooler air causes the condenser coil to operate at a lower temperature, and results in lower compressor energy and demand requirements.

Energy savings depend on the ambient humidity levels. Energy reductions of 8 to 11% have been estimated in climates generally warmer than southern Ontario's. Any reductions in energy or demand would occur during summer weather conditions, a time when refrigeration systems are subject to their heaviest loads. Demand savings at summer peak times may become of interest to some Ontario localities in the future.

The hardware is available now and has been used for many years, although the majority of the experience is in HVAC applications and in warmer regions than ours. Evaporative pre-cooling is suitable for retrofitting at reasonable cost and has proven reliable.

More experience is needed for applications in refrigeration systems and in climates such as ours. The potential energy and demand reductions may be further enhanced if installed system capacities are reduced, to account for the increase in refrigeration capacity when these evaporative pre-coolers are in use.

Electric Motor Compressor Drives

High efficiency electric motors can be used to replace existing motors on non-hermetic compressor systems. Efficiency improvements have generally been found to be between 3 to 8%. Savings are higher in situations where the motor is frequently running at less than full load.

This product has been on the market for years with proven field experience and reliability and is a good retrofit option. In most applications, associated fan motors are also good candidates for these high efficiency motors.

On an international basis, the addition of a fuel-fired (diesel or waste by-product) drive as a backup for peak load reduction has been tried. This is an option where savings from peak load reductions are significant although maintenance requirements may be high.

Passive Cooling

Passive cooling represents a unique cold-climate solution to the problem of refrigeration loads at the time of the utility's winter peak. Passive cooling can range from simple mechanical systems that circulate colder outside air into the chamber requiring refrigeration (turning off the normal refrigeration system), to more complex designs that use existing hardware and heat exchangers in combination with extra circulating pumps (uncompressed refrigerant is pumped between heat exchangers and acts as a heat transfer fluid). Pioneering work on this latter technology was

conducted under the Federal Department of Agriculture's "Energy Research and Development in Agriculture and Food" (ERDAF) program by Sunwell Engineering/98/. The concept has great potential for energy and demand reductions.

Passive cooling using ducted outside air is simple in concept, but in practice requires careful attention to achieve proper humidity control and acceptable air cleanliness. Ducting and cleaning costs are often too high in a retrofit situation to justify the use of outdoor air, but savings can be obtained if such passive cooling systems are incorporated into new plant designs.

Passive cooling using pumped refrigerant circulation is applicable to both retrofit and new-design situations. Although the hardware has only been tested in bench-scale demonstrations, one Canadian food processor is prepared to go ahead with such systems when (and if) economic forces justify the move. Since these systems use the refrigeration plant's existing heat exchangers and equipment, little change to the operation and control of the cooled space takes place.

In Canada, 50°F (10°C) processing rooms represent the greatest potential in terms of energy saving, because of the many hours-per-year that outdoor temperatures are below this value. Demand savings are dramatic, because all the system's compressors can be shut down, and the remaining electrical use (for pumps and fans) can have an effective refrigeration COP of over 100! In a typical application, this could result in the shedding of 500 hp of compressor load for a single room.

Overall, passive cooling represents one area likely to benefit most from Canadian utility strategic-conservation support. Pilot-demonstration projects are needed to obtain more information, and the technology is not likely to be developed by other countries with warmer climates than Canada's.

Potential energy and demand savings are dependent on the climate and the level of refrigeration required. For medium and high temperature applications in our climate, significant electrical demand reductions could be achieved. Field demonstration projects are needed to obtain more experience.

PROCESSING

All the items discussed under the two proceeding categories can apply here, in addition to the following:

New Refrigerants

The use of refrigerant R-502 to replace R-12 and R-22 for mid- to low-temperature applications has been tried successfully in the past. Usual results are an increase in overall cooling capacity and in some instances, a slight increase in overall efficiency.

More recently, the replacement of R-12 with R-500 in a large centrifugal refrigeration system has shown a 15% reduction in energy consumption with an 8% increase in capacity/97/.

It appears that there will be a significant increase in the work involving replacement refrigerants. The driving force behind this is the worldwide environmental concern with CFC's such as R-11, R-12 and R-113. Refrigerants such as R-502 are less of an environmental hazard and appear as likely retrofit candidates for most R-12 applications. The potential of energy savings, and demand reductions, will only accelerate this trend.

One disadvantage with these new refrigerants includes high cost (3 or more times R-12) and there are some concerns with compressor reliability (generally associated with effects on lubricants). As more field experience is gained, reliability concerns may be eliminated, as the majority of preliminary investigations show no adverse effects.

Compressors

Compared to the reciprocating type, rotary vane, dual-rotor helical screw and 'monoscrew' compressor designs may offer better energy and electrical demand performance. Generally, this better performance is achieved because of better part-load characteristics. These designs may also be better suited for higher-pressure applications than multistage reciprocating compressor systems.

Studies show significant energy reductions in the order of 20 to 30% using screw compressors compared to reciprocating compressors. Current availability of screw compressors is limited to a minimum capacity of approximately 50 tons, but future designs may be smaller.

Apparently, the potential for future efficiency improvements in reciprocating compressor technology is negligible.

Miscellaneous

Many refrigeration applications are specific to a particular process or local situation. The scale of the equipment (200 ton capacity and up) represents a large capital investment. Energy consumption and/or demand reduction potentials can involve large, absolute quantities.

For example, most ammonia refrigerant plants do not vary greatly in terms of basic design or hardware. In most cases, a general adherence to good refrigeration practices results in economically optimized, efficiently run systems. However, poor operation and maintenance procedures can result in damaged and poorly operating equipment that may eventually require major repair and refit work by an experienced mechanical consultant.

Significant variation in energy consumption does occur with the degree of partial load operation, which is highly dependent on the particular technique or product being processed. Studies have shown reduction in energy demand by optimizing compressor control methodology while satisfying changing process requirements. However, these are specific to one plant or process.

Changes to this type of refrigeration equipment to optimize demand reduction requires consideration of capital investment, product process performance and associated systems including heat recovery.

4.0 INDUSTRY CONTACTS*

As the second phase of the work, local people associated with the refrigeration industry were contacted. These people included consultants, contractors, compressor, valve and controls suppliers, and manufactures of commercial equipment. They were asked, in terms of energy consumption and demand reductions, their opinion on current and future hardware and systems developments.

A brief summary of the findings is listed under each sectoral category below.

RETAILING/FOOD SERVICE

The consensus here was that micro-processor controls will have a tremendous impact in the very near future. Of particular importance will be the effect on refrigerant control (electronic expansion valves) and defrost controls.

The question of environmental impact of refrigerants and the need to replace R-12 was mentioned. It is felt that this development may have a detrimental effect on the energy/demand situation.

The widespread acceptance of the parallel, unequal compressor system ('rack compressors') has left few opportunities in this area. The recent introduction of small capacity (10 ton) screw compressors will compete with new and retrofit applications that are now being fulfilled by 'rack compressor' systems.

Another 'energy crisis' could bring renewed interest in 'discretionary' energy conservation measures. These include system maintenance/optimization, use of strip curtains or enclosed display cases, etc.

WAREHOUSING/STORAGE

Again, a significant impact by computerized electronics in the controls field is foreseen. Computerized head pressure and refrigerant flow controls may become a popular retrofit product.

The availability of smaller capacity screw compressors and their excellent part load performance capabilities will take away a share of the reciprocating compressor market. The environmental concerns surrounding R-12 will result in many conversions to R-22 and R-502, but this will involve significant engineering to address concerns with fluid flows, oil return and compressor longevity. The popularity of ammonia systems will increase due to difficulties with CFC refrigerants and recent system improvements.

Some thoughts were also expressed in terms of a trend to a less conservative sizing of refrigeration plants. More applications of water cooled condensers with cooling towers are expected.

* See list of individuals contacted on page 17, following the references.

PROCESSING

Computerized control systems will have a big impact, especially with complex and variable product processes. Application of 'passive cooling' systems may be limited because of the cost and interactive effects with other systems in these plants. Subsidies could result in more demonstration studies.

5.0 CONCLUSIONS

Based on the information gathered through the literature search and industry contacts, short term (less than 3 years) and long term scenarios were developed for each sector. Demand reduction potential played a major role in the selections.

RETAILING/FOOD SERVICE

Short Term:

1.0 Computerized refrigerant flow control, defrost and compressor staging controls, especially for retrofit applications.

2.0 Parallel, unequal compressor systems with computerized staging controls.

3.0 Simple head pressure controls.

Long Term:

4.0 Variable speed compressor drives.

5.0 Replacement of reciprocating compressors with screw compressor designs.

6.0 Integrated computerized controls coordinating electronic expansion valves, head pressure and liquid level.

WAREHOUSING/STORAGE

Short Term:

7.0 Evaporative pre-coolers for air-cooled condensers (summer peak reduction).

8.0 Retrofit of passive cooling systems or techniques to existing refrigeration plants.

Long Term:

9.0 High efficiency electric motor drives for compressors and associated hardware.

10.0 Replacement or supplement of electric motor drives with fuel-fired mechanical drives.

11.0 Replacement of reciprocating compressors with screw or rotary compressor designs.

PROCESSING

Short Term:

12.0 Computerized integrated refrigeration and process controls.

13.0 Passive cooling systems, especially for high temperature (10 °C) applications.

14.0 Replacement and/or new types of refrigerants.

Long Term:

15.0 Integrated systems with thermal storage and heat recovery capabilities.

16.0 Supplementary fuel-fired mechanical compressor drives.

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